Radar Detection Of Near-Surface Buried Metallic Reflectors In Wet Soil

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For ground penetrating radar (GPR) sensing, with antennas positioned safely or conveniently above the surface, one must contend with the ground surface reflection as well as reflections from targets sought below it. Employing low enough frequencies to penetrate moist soil means resolution that will often not allow one to distinguish the surface from target return. New measurements at CRREL were analyzed using innovative methods to sucessfully reveal buried mine and mine-like targets in wet, rocky soil. With broad band short pulse illumination, one method used a simple model that predicted the expected waveforms when surface and target echoes interacted. The other method treated the same cases but proceeds from the observation that the total overlapping surface plus target return is distended in time relative to a reflection from the surface alone. By processing to define and isolate cumulative energy return over time, one could distinguish cases in which targets lay just below the surface. Both methods were successful with moist loamy soil. Performance of the second approach was also good in an extreme case, when seasonal effects were exploited.

INTRODUCTION

A fundamental problem in GPR sensing resides in the conflict between the need for good ground penetration and the desire for tolerable resolution. This translates into a question of frequency content. Lower frequencies penetrate wet ground more effectively with fewer scattering losses. At the same time, we desire higher frequencies for sufficient resolution. In this study, we assume that the sensing platform must have some (~ 2m or more) standoff from the ground surface, either for safety, to avoid disturbing the surface, or for ease of coverage. Thus the measured return will inevitably contain a ground surface reflection, particularly if, as in this study, we consider normal incidence. A reflector about one subsurface wavelength below the surface will generally produce a reflection that is difficult to separate from the ground surface return. The two returns will overlap in the time domain, with equivalent loss of discrimination in the frequency domain ([1],[2]). Viewing the scene from off-normal incidence does not entirely do away with the problem [3].

The problem is illustrated in Figure 1 which shows a ground surface reflection, above two depictions of returns from ground with a subsurface reflector. In each of these figures the trailing content is amplified by a factor of four with a ramp weighted transition zone between early and late time [2]. The reflector in this case is simply an assumed imperfectly reflecting interface below the surface layer with reflection coefficient of about –0.4. As shown below, this provided a reasonable rough approximation of the relative magnitude of response from some buried metallic reflectors. The top waveform is a measured signal, taken to correspond to the source wavelet used for computation of the lower two waveforms (center frequency 500 MHz ~ 600 MHz). We note that 1) over the three cases the signal is relatively unchanged in early time, which contains essentially only the ground surface reflection. Even with the late time amplification, early time contains the "brightest" part of the signal. Further amplification to detect trailing signal would likely bring up noise and false alarms. Thus in general one cannot search for near surface targets merely by looking for bright spots in radar records obtained over a surface area. 2) Even with a reflector at 20 cm depth it is not possible to distinguish separate reflections from surface and reflector, as needed for typical deconvolution operations. 3) The waveforms corresponding to different depths of reflector are distinct, being essentially interference patterns between surface and subsurface reflections. 4) When a reflector is just below the surface, the returned signal is distended in time relative to the source wavelet.
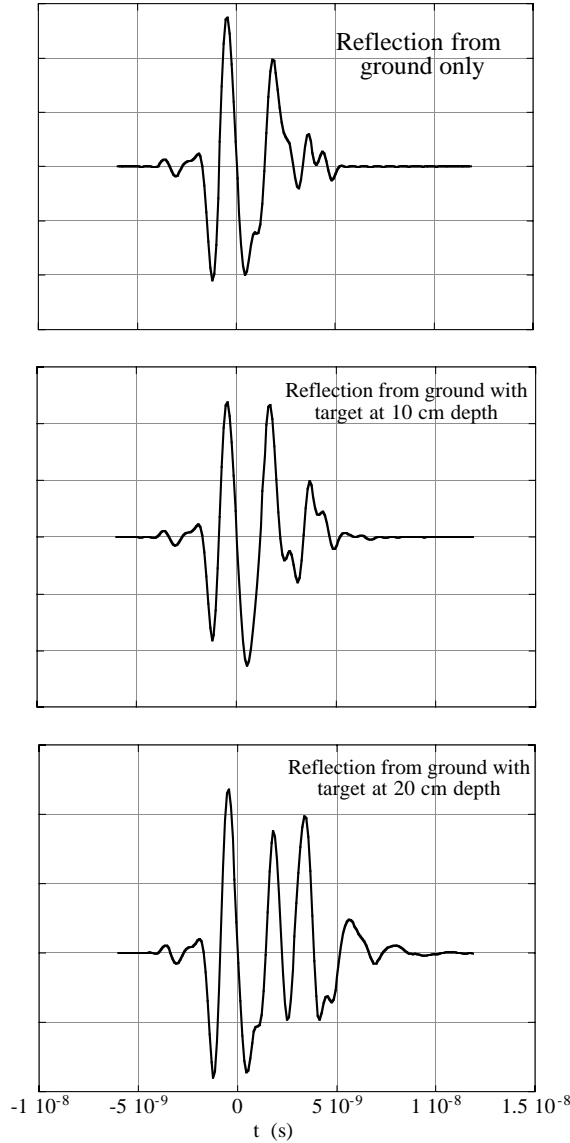
Figure 1. Wavelet reflected from ground surface without subsurface reflector (top) and with subsurface reflectors (middle and bottom). t denotes time.

## TWO METHODS FOR TARGET DISCRIMINATION

Waveform Recognition

As a first line of attack, we take inspiration from our modeling studies which suggest that, however obscured by other reflections, the returns contributed by our targets resemble the waveforms from a simple interface. As illustrated below, fine geometrical detail in the target tends to have only a higher order effect on the results. Using either the simple layer model or any more sophisticated treatment, one can compute a theoretical reference set of waveforms corresponding to reflectors at different possible depths, as in the lower two figures above. To evaluate the source of a measured signal, one determines which reference waveform correlates best with it. We use the simple interface model here, measuring soil moisture at about 16% by volume, corresponding to a dielectric constant of about 8, with frequency dependent lossiness corresponding to the volume fraction of water. An effective target reflection coefficient of about –0.4 was again assumed for top of the target.

Figure 2 shows the results of applying this system to three measurements: The top applies to reflections from a moist soil with no subsurface target other than
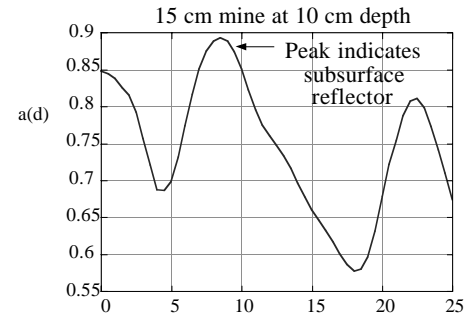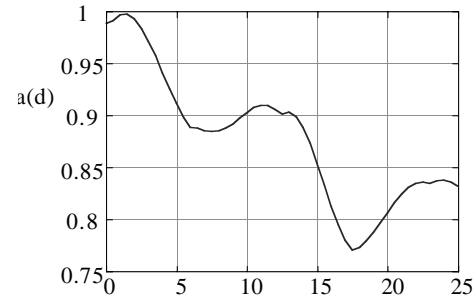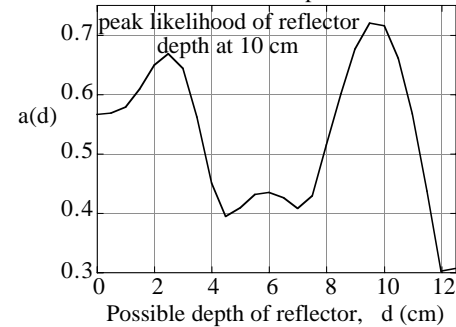

Figure 2. Computed correlation of measured with reference waveforms (a) as a function of depth (d).

natural rock clutter. The middle and bottom (respectively) are from a 15 cm diamter metallic mine and a 30 cm diameter model of an anti-tank mine, both buried at 10 cm depth.

The signal reflected from ground alone correlates approximately 100% for depth $d \sim 0$. That is, it virtually perfectly matches a theoretical return based on the assumption that reflection comes from the surface only. For the 15 cm mine one sees a significantly lower correlation for $d \sim 0$, and a peak correlation corresponding to a 10 cm deep target. For the anti-tank mine model the correlation with surface return alone is quite low, and the peak correlation matches the correct depth quite closely. In effect, the modeling/ signal processing allows us to recover some of the resolution that is lost when we must resort to relatively low frequencies.

Energy Distention

Another approach depends less on any particular scattering model, but works simply from the realization that a the surface return will be distended by a shallow buried scatterer.

By squaring and smoothing signals like those in Figure 1, each normalized to have unit energy, one obtains a record of "energy" accumulation through time. Figure 3 shows the results of such procedures, applied to reflections from the moist soil without a buried target, and from the same soil containing alternative metallic targets of comparable size. The same radar system was used as produced the pulse at the top of Figure 1. When there is no subsurface target the returned energy accumulates relatively quickly. Otherwise we note
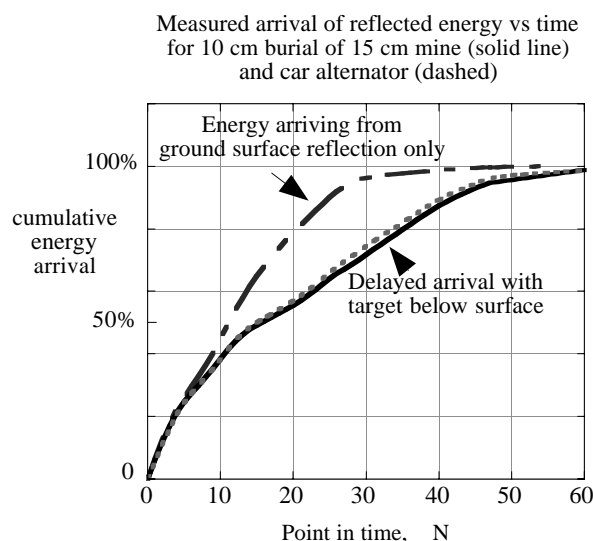
a characteristic delay in the approach to 100% arrival. That delay is not significantly dependent on target details. While both are axisymmetric, the mine is relatively smooth with a simple central cylindrical rise. The alternator contains a drive wheel with protruding rod, and other features reminiscent of various more complex mine morphologies. In either case the presence of the target is clear, by virtue of the trajectory of energy arrival. Similar experiments with other shapes and sizes of target at other depths proved likewise successful.

It has been noted that GPR techniques fared quite poorly in locating buried unexploded ordnance in recent advanced technology demonstrations. This has been ascribed in part to wet clay soil at the survey site [4]. Clays can have electrically active particles, and can retain much more water than other soils, with commensurately greater reflectivity and lossiness. To investigate this together with seasonal effects, test plots were constructed with an extremely wet clayey soil (moisture content in excess of 40% by volume), at the US Army Cold Regions Research and Engineering Laboratory, in Hanover, NH, USA. Metallic targets of the general size and shape of anti-tank mines (30 to 35 cm across) were buried at $d \sim 13$ cm, and radar reflections were measured under both frozen and unfrozen conditions. Figure 4 shows results along survey transects in which the radar was above the target on the left side of the figure, then was moved away producing the scans on the right. N_{85} represents the time point within the trailing signal content at which the cumulative energy return of the signal segment reaches 85% of its ultimate value (cf Figure 3). The target is essentially invisible in the wet clay, but shows very clearly in the pattern of N_{85} when the soil is frozen.

Measured arrival of reflected energy vs time
for 10 cm burial of 15 cm mine (solid line)
and car alternator (dashed)

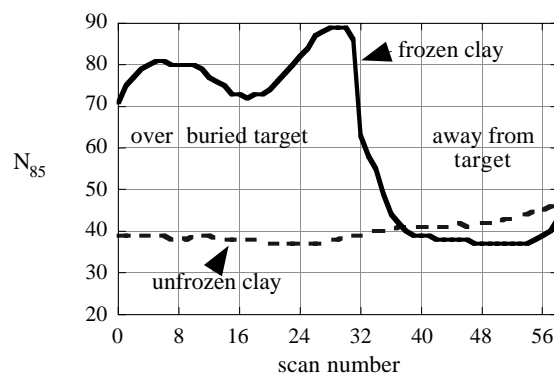Figure 3. Time trajectories of cumulative energy arrival

Figure 4. Point of 85% cumulative energy arrival (N_{85}) as a function of scan number for buried anti-tank mine models, when clayey soil is frozen or unfrozen.

CONCLUSION

In seeking to discriminate near-surface metallic targets on the order of the subsurface incident wavelength in size, the methods pursued here were successful in applications in moist soil of mixed type. Signal processing with or without modeling was required to interpret radar returns; one could not simply look for bright spots in the record. In the extreme case of very wet clay, it appears that returns from mine-like targets can still be distinguished from overlapping surface reflections, under frozen conditions. We anticipate improvement against some of the near false alarms (eg secondary peaks in Figure 2) by improvement of the reference signal set, either through more sophisticated modeling or incorporation of field data.

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